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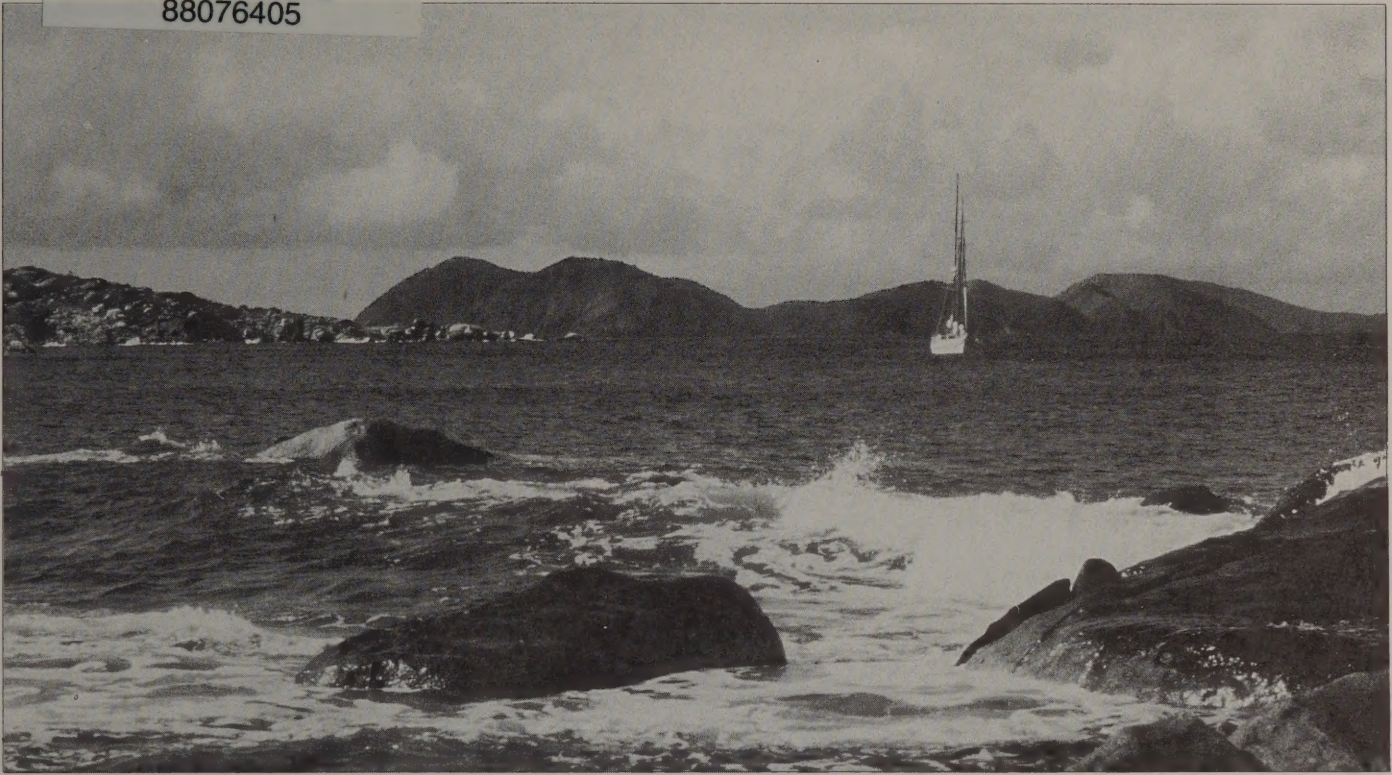

MAGNESIUM AND MAGNESIUM COMPOUNDS

By Deborah A. Kramer

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MAGNESIUM AND MAGNESIUM COMPOUNDS

U.S.
DEPARTMENT
OF THE
INTERIOR

Manuel Lujan, Jr.
Secretary

BUREAU
OF
MINES

T S Ary
Director

October 1991

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COVER PHOTO:
Seawater represents a vast resource of magnesium. With a concentration of 0.13%, magnesium is the third most abundant element dissolved in seawater. In many countries, plants producing magnesium metal and magnesium compounds are on the coast to take advantage of this renewable resource.

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MAGNESIUM AND MAGNESIUM COMPOUNDS

By Deborah A. Kramer

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Domestic production of primary magnesium decreased by about 8% in 1990 because U.S. producers faced competition from increasing quantities of imports, primarily from Canada. Two primary magnesium facilities opened in Canada during the year, increasing annual world production capacity by 52,500 metric tons. Most of the magnesium produced at these plants was exported to the United States, resulting in a dramatic increase in the quantity of total imports in 1990.

Aluminum alloys remained the principal end use for magnesium, but diecastings showed the largest increase in primary magnesium consumption between 1989 and 1990. Magnesium diecastings were used in a greater number of automotive applications, because automakers looked to reduce total vehicle weight without reducing vehicle size. The potential for a significant increase in Corporate Average Fuel Economy standards in the near future could result in an even larger increase in magnesium consumption by the U.S. automotive industry.

Domestic production and consumption of magnesium compounds declined slightly in 1990. Imports supplied about 25% of domestic demand, about the same as in 1989, although the total quantity of imports decreased.

Seawater and brines were the principal raw materials used to manufacture magnesium compounds, accounting for about 69% of the total, with dolomite, magnesite, and olivine as the other sources. Refractories were the largest use for dead-burned magnesia; caustic-calcined magnesia principally was used in the agricultural and chemical industries.

Producers in Czechoslovakia, Ireland, and Mexico were upgrading their facilities to produce higher grade dead-burned magnesia for consumers throughout the world in the iron and steel, nonferrous metals, cement, and glass industries. In general, these consumers were seeking material with high magnesium oxide (MgO) content, low boron content, and large particle size.

DOMESTIC DATA COVERAGE

Data for magnesium metal are collected from two voluntary surveys of U.S. operations. Of the 129 companies canvassed for magnesium consumption data, 97% responded, representing 65% of the primary magnesium consumption shown in tables 4 and 6. Data for the four nonrespondents were estimated based on prior-year consumption levels and other factors.

Data for magnesium compounds were collected from one voluntary survey of U.S. operations. Of the 20 companies canvassed, 90% responded, representing 70% of the magnesium compounds shipped and used shown in table 14. Data for the two nonrespondents were estimated based on prior-year consumption levels and other factors.

BACKGROUND

Definitions, Grades, and Specifications

Primary magnesium metal contains a minimum of 99.8% magnesium. Magnesium-base alloys are named by the composition of the two chief alloying elements, each designated by a letter, and the approximate percentage of each alloying element. For example, AZ91 contains about 9% aluminum (A) and 1% zinc (Z), and HK31 contains about 3% thorium (H) and 1% zirconium (K). Other letters used in specifying magnesium alloys are E for rare-earth metals and M for manganese.

Magnesite, or magnesium carbonate ($MgCO_3$), has a theoretical magnesium content of 47.6%. Dolomite is a calcium carbonate-magnesium carbonate mineral ($CaCO_3 \cdot MgCO_3$) that has a theoretical magnesium content of 22%. Brucite, magnesium hydroxide [$Mg(OH)_2$], contains up to 69% magnesium, and olivine ($Mg_2Fe_2SiO_4$) contains up to 19% magnesium. Of these minerals, magnesite and dolomite are the largest sources of magnesium and magnesium compounds.

Seawater, brines, and bitterns represent vast sources of magnesium and magnesium compounds. In the United States, more than 60% of the magnesium compounds produced annually are recovered from seawater and brines, and 80% of the magnesium metal production capacity uses seawater or brines as a raw material.

Various magnesia products are made by calcining magnesium carbonate or magnesium hydroxide at different temperatures. Caustic-calcined magnesia, which is readily reactive with water, is calcined at temperatures up to 890° C. Dead-burned magnesia, also called refractory or sintered magnesia, is calcined at temperatures up to 1,450° C and is unreactive with water. Fused magnesia is produced at temperatures greater than 3,000° C. Magnesia produced from magnesite is generally called natural magnesia, and magnesia produced from seawater or brines is called synthetic magnesia.

Standards for magnesia, including chemical composition, bulk density, and particle size, generally are set by the consumer for a specific application. Refractory magnesia composition depends on the area of the furnace in which the material is to be used. Magnesia produced from magnesite can contain between 88% and 98% magnesia, with varying quantities of silica, iron, calcium, and alumina impurities. Synthetic magnesia normally is purer than natural magnesia, containing between 92% and 99.5% magnesia, with smaller quantities of the same impurities found in natural magnesia. Most fused magnesia contains greater than 94% magnesia.

Products for Trade and Industry

The principal use for magnesium metal, averaging greater than 50% of U.S. consumption annually, is as an alloying addition to aluminum. Magnesium improves the hardness and corrosion resistance of pure aluminum. Aluminum-magnesium alloys are used in a variety of applications, including automobiles, trucks, aircraft, appliances, and home siding. Two-piece beverage cans, containing about 2% magnesium, are the largest single use for these aluminum-magnesium alloys.

Magnesium and its alloys are used as structural components on automobiles, trucks, aircraft, computers, and power tools. Many of these applications use magnesium because of its light weight and ease of machinability. Magnesium is used in the iron and steel industry for external hot-metal desulfurization and in the production of nodular iron. Production of the nonferrous metals, beryllium, hafnium, titanium, uranium, and zirconium, involves the use of magnesium as a reducing agent. Anodes of magnesium are used for cathodic protection of underground pipe and water tanks. Small quantities of magnesium are used as a catalyst in producing organic compounds, as photoengraving plates, and in alloys other than aluminum.

Refractory magnesia represents the largest use of magnesium in compounds. Refractory magnesia is manufactured into bricks and other shapes, principally for linings in furnaces and auxiliary equipment used to produce iron and steel. Magnesia-base refractories also are used in furnaces in the cement, glass, and nonferrous metals industries.

Caustic-calcined magnesia is used in a variety of applications in the agricultural, chemical, construction, and manufacturing industries. Caustic-calcined magnesia is an important component of animal feed and fertilizer, providing essential nutrients for livestock and plant growth. In construction, caustic-calcined magnesia is used in special cements for industrial flooring and in lightweight insulating wallboard. In the chemical industry, it is used as a starting point for the manufacture of other magnesium salts. Special grades of caustic-calcined magnesia are used for pharmaceuticals, including antacids, toothpaste, milk of magnesia, and cosmetics. Magnesia is used to remove sulfur from flue gases and boiler fuels and is used for acid neutralization in process wastewater and in lubricating oils. Caustic-calcined magnesia is also important in manufacturing paper, rayon, and rubber.[1]

Other magnesium compounds are used in place of, or in addition to, caustic-calcined magnesia in many of the above applications. Magnesium hydroxide is used in the pulp and paper industry; magnesium sulfate is used for pharmaceuticals, animal feed, and fertilizers; and magnesium carbonate is used in the chemical, pharmaceutical, and rubber industries. Fused magnesia is used primarily for electrical insulation.

The principal use for olivine is as a foundry sand used in casting iron and steel components and some nonferrous metals. Olivine is used in smaller quantities for refractories, slag control in blast furnaces, and soil conditioning. In Europe, olivine is used instead of sand for blasting debris from bridges and buildings and in incinerators.[2]

Industry Structure

U.S. producers of magnesium and magnesium compounds are shown in tables 1 and 2. Olivine is produced by two companies in the United States—Applied Industrial Minerals Corp. (AIMCOR) and Olivine Corp. AIMCOR operates two mines and processing plants in Indiana, North Carolina, and Washington, and Olivine operates one mine and one processing plant in Washington.

Electrolytic plants in Canada, Norway, the U.S.S.R., and the United States represent 75% of the world magnesium metal production capacity. Smaller thermal plants are in Brazil, Canada, China, France, India, Italy, Japan, and Yugoslavia.

The largest magnesite production facilities in the world are in China, North Korea, and the U.S.S.R. Together, these three countries account for 53% of the world magnesite production capacity. Japan and the United States account for 58% of the world's magnesium compounds production capacity from seawater or brines. Fused magnesia is produced in Canada, France, Israel, Japan, the United Kingdom, and the United States.

Norway is the world's principal producer of olivine, and in addition to supplying its domestic needs, Norway is a major world supplier of this mineral. Countries with smaller output are Austria, Italy, Japan, Mexico, Spain, Sweden, and the United States.

Geology

Magnesium is the eighth most abundant element and constitutes about 2% of the Earth's crust. It is the third most plentiful element dissolved in seawater, with a concentration averaging 0.13%. Although many minerals contain magnesium, magnesite, dolomite, brucite, and olivine are the only minerals from which magnesium compounds are recovered commercially.

Dolomite is a sedimentary rock commonly interbedded with limestone, which extends over large areas of the United States. Most dolomite occurrences are likely the result of replacement of calcium by magnesium in preexisting limestone beds. Magnesite primarily is found in four types of deposits: sedimentary beds, alterations of serpentine, vein fillings, and replacements of limestone and dolomite. Brucite is found in crystalline limestone and as a decomposition product of magnesium silicates associated with serpentine, dolomite, magnesite, and chromite. Olivine generally occurs as granular masses or disseminated grains or crystals and is a common constituent of basic igneous rocks such as basalt and gabbro. Dunite is an olivine-rich rock.[3]

Technology

***Processing.*—Metal.**—Two thermal processes currently are in use to recover magnesium metal from dolomite—the Pidgeon process and the Magnetherm process. Both use the same basic chemistry, but the Pidgeon process uses an external heat source, and the Magnetherm process uses heat generated by the electrical resistance of the reactants. In the Pidgeon process, dolomite and ferrosilicon are formed into briquettes and heated in a retort under a vacuum. Magnesium oxide in the dolomite reacts with the ferrosilicon to produce magnesium vapor, which is cooled and condensed in a separate section of the retort. Plants in

TABLE 1

U.S. MAGNESIUM METAL PRODUCERS, BY LOCATION, RAW MATERIAL, AND PRODUCTION CAPACITY IN 1990

Company	Plant location	Raw material	Annual capacity (metric tons)
The Dow Chemical Co.	Freeport, TX	Seawater	109,000
Magnesium Corp. of America	Rowley, UT	Lake brines	35,000
Northwest Alloys Inc.	Addy, WA	Dolomite	35,000
Total			179,000

TABLE 2

U.S. MAGNESIUM COMPOUND PRODUCERS, BY RAW MATERIAL SOURCE, LOCATION, AND PRODUCTION CAPACITY IN 1990

Raw material source and producing company	Location	Capacity (metric tons of MgO equivalent)
Magnesite: Basic Inc.	Gabbs, NV	100,000
Lake brines:		
Great Salt Lake Minerals & Chemicals Corp.	Ogden, UT	90,000
Reilly Industries Inc.	Wendover, UT	45,000
Well brines:		
The Dow Chemical Co.	Ludington, MI	200,000
Martin Marietta Chemicals	Manistee, MI	300,000
Morton Chemical Co.	do.	10,000
Seawater:		
Barcroft Co.	Lewes, DE	5,000
Basic Magnesia Inc.	Port St. Joe, FL	50,000
The Dow Chemical Co.	Freeport, TX	20,000
Marine Magnesium Co.	South San Francisco, CA	15,000
National Refractories & Minerals Corp.	Moss Landing, CA	177,000
Total		1,012,000

Canada, Italy, and Japan use this process to recover magnesium.

In the Magnetherm process, calcined dolomite, ferrosilicon, and alumina are heated under a vacuum. Alumina reduces the melting point of the slag produced by the dolomite-ferrosilicon reaction to make resistance heating practical. Magnesium vapor is cooled and condensed in a condensing chamber. The Magnetherm process is used in plants in Brazil, France, Japan, the United States, and Yugoslavia.

Electrolytic recovery of magnesium requires a magnesium chloride feedstock that normally is prepared from seawater or brines. Two types of magnesium chloride can be made—hydrous and anhydrous. In the preparation of hydrous magnesium chloride, used by Dow Chemical Co., magnesium hydroxide is precipitated from seawater by the addition of dolomitic limestone. Adding hydrochloric acid to the magnesium hydroxide produces a neutralized magnesium chloride solution. This solution is dehydrated until it contains about 25% water and is fed directly to electrolytic cells.

Magnesium Corp. of America (MagCorp) and Norsk Hydro A/S use an anhydrous magnesium chloride feed for their electrolytic cells. MagCorp uses solar evaporation initially to concentrate magnesium chloride brines from the Great Salt Lake. After adding calcium chloride to precipitate sulfate impurities and removing boron by solvent extraction, the brine is concentrated further and dehydrated in a spray dryer. The resulting powder is purified, concentrated, prilled, and dehydrated to produce anhydrous magnesium chloride.[4] Norsk Hydro starts with concentrated magnesium chloride brine. The brine is purified, concentrated, prilled, and dehydrated to produce anhydrous magnesium chloride.

Electrolytic cells used to recover magnesium from either hydrous or anhydrous magnesium chloride differ from company to company, and most information about cell design and operating conditions usually are not disclosed. Essentially, magnesium chloride fed to an electrolytic cell is broken down into magnesium metal and chlorine gas by direct current at 700° C. Magnesium is removed from the cell and cast into ingots, and the chlorine gas is recycled or sold.

Magnesium International Corp. developed a one-step process for producing anhydrous magnesium chloride that was demonstrated at Magnesium Co. of Canada Ltd.'s (MagCan) new plant that opened in 1990. Reacting magnesite with chlorine gas in the presence of carbon monoxide in a packed-bed reactor at 900° C produces magnesium chloride and carbon dioxide. Liquid magnesium chloride collects at the bottom of the reactor and is tapped periodically for transfer to electrolytic cells.[5]

Nonmetal.—Preparing either caustic-calcined or dead-burned magnesia from magnesite involves crushing the magnesite to various sizes, depending on the type of material to be produced. After crushing, magnesite is beneficiated; the degree of beneficiation depends on the quality of the ore and its ultimate end use. Lower quality ore often requires heavy-media separation, magnetic separation, and flotation to remove impurities. High-quality ore may require only screening and hand sorting to produce a material of acceptable quality. Caustic-calcined magnesia is produced in shaft kilns, multiple-hearth furnaces, or rotary kilns. Dead-burned magnesia is produced in rotary or shaft kilns.

In producing synthetic magnesia, seawater or brines are treated either with a small quantity of lime or sulfuric acid to remove dissolved carbon dioxide. Then calcium hydroxide, in the form of lime or dolime, is added to precipitate the dissolved magnesium as magnesium hydroxide. The resulting slurry is thickened and vacuum filtered to yield a filter cake containing about 50% magnesium hydroxide. The filter cake can be directly calcined to produce caustic-calcined or dead-burned magnesia, or it can be calcined and pelletized before dead-burning to give specific size and density characteristics.

Fused magnesia is produced by fusion of high-grade magnesite or caustic-calcined synthetic magnesia in an electric arc furnace. After fusion, the material is crushed, inspected to remove any unfused magnesia, and crushed further in a ball mill.

Economic Factors

Costs to produce magnesium metal vary greatly, depending on the feed material and the process used. Operating costs for magnesium production range from $309 to $2,283 per ton, with energy costs as the largest component of the total operating cost. Total production costs from seawater sources were lower than from brines or dolomite sources. Magnesium compound operating costs also vary depending on source material and processing techniques. Operating costs range from $24 to $425 per ton for magnesium compound production, with seawater as the most costly source. Energy costs also represent the largest component of total operating costs.[6]

Tariffs for magnesium and magnesium compounds are shown in table 3. Depletion allowance for magnesium chloride from domestic or foreign sources is 5%. Magnesium carbonate and dolomite have depletion allowances of 14% from domestic and foreign ores. Depletion allowances for other ores are brucite, 10% (domestic and foreign); and olivine, 22% domestic and 14% foreign.

ANNUAL REVIEW

Magnesium

Legislation and Government Programs.—On January 23, the Environmental Protection Agency (EPA) finalized rules proposed in September 1989 on the regulation of 20 special wastes from mineral processing under subtitle C of the Resource Conservation and Recovery Act (RCRA). Process wastewater from primary magnesium by the anhydrous process was temporarily excluded from regulation under subtitle C of RCRA. In a draft report to Congress, prepared by EPA in August, the Agency recommended that this waste product be regulated under subtitle D of RCRA.[7]

Production.—Domestic production of primary magnesium declined by about 8% and was about 78% of rated yearend capacity. An increase in U.S. imports of magnesium from new plants in Canada and an effort from the domestic producers to control their inventory levels were partially responsible for the production decrease.

Dow announced that its magnesium businesses, which did not have a formal corporate identity, were officially united under the name Dow Magnesium. The company also planned to invest an estimated $16 million in its Freeport, TX, facility to broaden its product line. One of the components to be added was a 50-million-pound-per-year direct chill vertical caster. It would enable Dow to produce T-bar ingot in sizes greater than 250 pounds and would allow production of primary and alloyed round billet. Caster installation was expected to be completed in the first quarter of 1992.

Consumption and Uses.—Although consumption of primary magnesium decreased slightly in 1990, the use of magnesium diecastings continued to grow as more applications were developed,

TABLE 3

U.S. IMPORT DUTIES

Item	HTS No.	Most favored nation (MFN)	Non-MFN
		Jan. 1, 1990	Jan. 1, 1990
Magnesium:			
Unwrought magnesium	8104.11.0000	8.0% ad valorem	100% ad valorem.
Unwrought magnesium alloys	8104.19.0000	6.5% ad valorem	60.5% ad valorem.
Magnesium waste and scrap	8104.20.0000	Free	Free.
Wrought magnesium	8104.90.0000	14.8 cent per kilogram on Mg content + 3.5% ad valorem	88 cent per kilogram on Mg content + 20.0% ad valorem.
Magnesium compounds:			
Crude magnesite	2519.10.0000	Free	$10.33 per ton.
Dead-burned and fused magnesia	2519.90.1000	0.4 cent per kilogram	1.7 cent per kilogram.
Caustic-calcined magnesia	2519.90.2000	$2.07 per ton	$20.70 per ton.
Other magnesia	2519.90.5000	Free	15.4 cent per kilogram.
Calcined dolomite	2518.20.0000	6% ad valorem	30% ad valorem.
Kieserite, natural	2530.20.1000	Free	Free.
Epsom salts, natural	2530.20.2000	3.7% ad valorem	20% ad valorem.
Magnesium hydroxide and peroxide	2816.10.0000	3.1% ad valorem	25% ad valorem.
Magnesium chloride	2827.31.0000	1.5% ad valorem	5% ad valorem.
Magnesium sulfate	2833.21.0000	3.7% ad valorem	20% ad valorem.

TABLE 4

SALIENT MAGNESIUM STATISTICS

(Metric tons unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Production:					
Primary magnesium	125,639	124,396	141,983	152,066	139,333
Secondary magnesium	41,807	45,164	50,207	51,200	54,529
Exports	39,909	44,182	49,802	56,631	51,834
Imports for consumption	8,355	10,851	14,407	12,289	26,755
Consumption, primary	78,961	94,620	100,793	105,226	96,108
Price per pound	$1.53	$1.53	$1.58–$1.63	$1.63	$1.43–$1.63
World: Primary production	322,408	323,930	[r]334,348	[r]344,043	[e]351,198

[e]Estimated. [r]Revised.

particularly in the automotive industry. The current estimate of the magnesium content of U.S.-produced vehicles was about 4 pounds per vehicle, but this was expected to increase significantly within the next few years.

General Motors Corp. planned to introduce new V-8 engines in some of its 1992 Cadillac models that contain about 5 pounds of magnesium, and the automaker announced that these cars would contain an additional 10 pounds of magnesium in the induction system and the transmission. Chrysler Corp. used magnesium diecastings for the accessory drive brackets in its 2.5- and 4.0-liter 1991 Jeep engines. Using magnesium to replace aluminum in these components represented a weight savings of 2.75 pounds per vehicle. Dow produced a prototype magnesium V-8 engine block that weighed less than 50 pounds for the Dow-owned demonstration Corvette to promote the advantages of using magnesium in automotive applications. The prototype engine block replaced a 135-pound standard cast-iron engine block.[8]

Foreign auto manufacturers also were using magnesium in several applications. Audi AG of the Federal Republic of Germany equipped some of its sedans with a magnesium dashboard bulkhead, which was one of the most critical structural components of the car's body. By using magnesium, tooling requirements and additional fabrication costs could be reduced. Nissan Motor Co. of Japan developed an alumina-reinforced magnesium piston that could yield a 40% weight reduction from conventional cast-iron pistons. Normally magnesium is not suitable for parts that are subject to a lot of wear, but by adding alumina reinforcement, it became about five times as wear-resistant as aluminum.

To capitalize on the interest on magnesium in structural applications such as automotive components, two research and development centers opened in 1990. The Institute of Magnesium Technology Inc. in Sainte-Foy, Quebec, officially opened in September. The Institute is funded by its membership, which consisted of primary producers, processors, converters, and users, and by the Canadian Government. Its principal function is to conduct research for the private and public sectors and to expand the world markets for magnesium products.[9] Norsk Hydro opened its Magnesium Market Development Center in Southfield, MI, in January. The center's main goal is to provide more comprehensive service to end users, especially in the automotive industry, and to work with the end users to develop new applications for magnesium. In addition to equipment at the center, Norsk Hydro will be able to use the resources of the Institute of Magnesium Technology Inc., of which it is a member.

Nippon Light Metal Co. and Diemakers Inc. planned to establish joint ventures in the United States and Japan to collaborate on the development, manufacturing, and marketing of magnesium die-cast products. The U.S. joint venture, to be called Nikkei Diemakers USA and funded 65% by Diemakers and 35% by Nippon Light Metal, will promote sales of magnesium diecastings to Japanese automakers operating in the United States. The Japanese joint venture, Nikkei Diemakers Co., funded 65% by Nippon Light Metal and 35% by Diemakers, will provide technical services and support for sale of Diemakers' products in Japan. Diemakers was acquired in May by Kanematsu USA Inc., a wholly owned subsidiary of the Japanese trading company Kanematsu Corp., and it reportedly was the third largest magnesium diecastings producer in the United States.

Bicycle frames were another emerging use for magnesium. In the *Tour de France* run during the year, some entrants rode bicycles with magnesium frames and claimed that the bicycles were very durable in crashes and could corner faster than conventional racing bicycles. A process to make a one-piece bicycle frame that took 52 seconds to complete was developed in the United Kingdom. In the process, molten magnesium was quickly injected into a mold and allowed to solidify there. Traditionally, individual sections of aluminum or steel were welded together to construct the frame. With the increased interest in magnesium bicycles, Norsk Hydro planned to construct a plant in Chelmsford, United Kingdom, to produce magnesium bicycle frames. Plant construction was expected to be completed early in 1991.

Dow Magnesium announced that it would stop production of its Pelamag™ granules at the beginning of 1991. The granules consisted of a spherical core of magnesium encased in a coating of mixed inorganic salts and were used for steel desulfurization. The capacity at the company's Freeport, TX, plant was expected to be used to produce other magnesium products that were preferred for desulfurization.

In April, Reactive Metals & Alloys Corp. (REMACOR) announced the sale of its Reade Manufacturing Div. to Magnesium Elektron Ltd., a unit of Alcan Aluminium Ltd. Reade Manufacturing produced magnesium powder, chips, and granules and supplied these materials to REMACOR for manufacturing desulfurization reagents. The transaction included a long-term contract for Reade Manufacturing to continue supplying REMACOR with its magnesium powder requirements.

Because of a combination of characteristics, including light weight, strength, and durability, magnesium was selected as the housing for the first totally self-powered

TABLE 5

MAGNESIUM RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1986	1987	1988	1989	1990
KIND OF SCRAP					
New scrap:					
Magnesium-base	991	845	2,641	3,951	3,992
Aluminum-base	17,822	20,867	19,926	19,278	19,464
Total	18,813	21,712	22,567	23,229	23,456
Old scrap:					
Magnesium-base	3,958	3,857	3,882	4,269	4,277
Aluminum-base	19,036	19,595	23,758	23,702	26,796
Total	22,994	23,452	27,640	27,971	31,073
Grand total	41,807	45,164	50,207	51,200	54,529
FORM OF RECOVERY					
Magnesium alloy ingot[1]	3,925	4,001	3,930	4,494	4,290
Magnesium alloy castings	551	447	438	795	857
Magnesium alloy shapes	31	—	1,065	635	301
Aluminum alloys	37,293	40,711	43,827	43,125	46,528
Zinc and other alloys	3	W	W	W	W
Chemical and other dissipative uses	W	W	943	W	W
Cathodic protection	W	—	W	W	W
Total	41,807	45,164	50,207	51,200	54,529

W Withheld to avoid disclosing company proprietary data; included in "FORM OF RECOVERY: Total."

[1] Includes secondary magnesium content of both secondary and primary alloy ingot.

radar detector, produced by Cincinnati Microwave Inc. The magnesium housing, die-cast in three pieces with no additional machining required, weighed 1.5 ounces before assembly. Cincinnati Microwave's goal was to create a receiver that would fit in a shirt pocket, take abuse, and operate by battery power alone for months.

Stocks.—Consumer stocks of primary magnesium ingot rose from 5,350 tons at yearend 1989 to 5,428 tons at yearend 1990. Consumer stocks of magnesium alloy ingot also increased from 849 tons at yearend 1989 to 879 tons at yearend 1990. Producer stocks of primary magnesium decreased slightly from 20,133 tons at yearend 1989 to 19,535 tons at yearend 1990.

Markets and Prices.—Quoted producer prices for both primary magnesium and diecasting alloy, AZ91D, remained stable during most of the year. Primary magnesium was quoted at $1.63 per pound, and diecasting alloy was quoted at $1.43 per pound. In December, Dow announced that it was reducing its price by 20 cents to $1.43 per pound, effective December 3 for spot customers and as terms permit for contract customers. The company cited the need to bring quoted prices closer to actual market prices in both the United States and abroad. MagCorp maintained its primary magnesium price at $1.63 per pound. At yearend, primary magnesium was quoted at $1.43 to $1.63 per pound, and diecasting alloy was quoted at $1.43 per pound.

Foreign Trade.—Plant openings in Canada resulted in a dramatic increase in imports of primary metal from that country. Canada supplied 76% of the total U.S. magnesium imports in 1990, which more than doubled from the 1989 level. Although total magnesium exports decreased, the United States remained a net exporter of magnesium in 1990.

World Review.—According to the International Magnesium Association, world inventories of primary magnesium rose to 43,800 tons at yearend 1990 from 35,000 tons at yearend 1989. Yearend 1990 inventories represented a 63-day supply compared with a 52-day supply at yearend 1989.

Canada.—Norsk Hydro Canada Inc., a unit of the Norwegian firm Norsk Hydro, reportedly reached full-scale production by the end of June at its new 40,000-ton-per-year magnesium plant in Becancour, Quebec. By the end of March, the plant was producing a variety of pure magnesium and magnesium alloy products. In addition, magnesium produced at the plant entered the qualification stages with the major aluminum-can-stock producers. Near the end of the year, Norsk Hydro announced that it would expand its casting facilities at the Becancour plant to include production of magnesium alloy billet in addition to primary magnesium billet. This expansion, planned for completion in 1992, would give the plant a total annual billet production capacity of 30,000 tons. The company also announced that it would spend $6 million to construct a magnesium recycling plant to process home scrap as well as scrap from customers. The recycling plant was scheduled to reach full operation by 1992.

During 1990, MagCan was plagued with operational problems at its new magnesium plant in High River, Alberta. Initially MagCan had planned to be operating at its full capacity of 12,500 tons per year by the end of the first quarter, but was only running at about one-third of design capacity by the end of April because the plant was unable to get enough power out of the reactor transformers. Because of these problems, Alberta Natural Gas Co., one of the equal-share partners in the MagCan project along with Magnesium International Corp., reportedly invested an additional $40 to $45 million in the project in September to take a controlling interest. MagCan reached an operating rate of 6,250 tons per year for 2 weeks in December until technical problems with some of the equipment occurred, and the company was forced to curtail production. Despite these operational problems, MagCan expected that production would reach its full capacity by mid-1991.

Noranda Inc. and Lavalin Industries reportedly were seeking a third partner in a joint-venture project to construct a 50,000-ton-per-year magnesium plant in East Broughton, Quebec. The companies

TABLE 6

U.S. CONSUMPTION OF PRIMARY MAGNESIUM, BY USE

(Metric tons)

Use	1986	1987	1988	1989	1990
For structural products:					
Castings:					
Die	3,646	3,710	4,383	5,627	7,479
Permanent mold	748	1,121	943	811	875
Sand	1,373	1,454	1,743	1,017	724
Wrought products:					
Extrusions	6,285	6,804	6,907	6,712	7,848
Other[1]	[r]1,452	[r]1,496	[r]3,231	[r]2,941	3,096
Total	[r]13,504	[r]14,585	[r]17,207	[r]17,108	20,022
For distributive or sacrificial purposes:					
Alloys:					
Aluminum	[r]39,290	[r]52,172	[r]53,671	[r]53,821	45,060
Other	5	8	7	9	8
Cathodic protection (anodes)	6,342	5,537	6,234	5,474	5,421
Chemicals	1,449	1,047	780	594	800
Iron and steel desulfurization	[e]9,000	[e]10,000	W	10,463	9,853
Nodular iron	1,622	1,811	2,037	1,635	1,424
Reducing agent for titanium, zirconium, hafnium, uranium, beryllium	5,235	5,286	8,467	10,798	8,989
Other[2]	2,514	4,174	12,390	5,324	4,531
Total	[r]65,457	[r]80,035	[r]83,586	[r]88,118	76,086
Grand total	78,961	94,620	100,793	105,226	96,108

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data; included in "Other."

[1]Includes sheet and plate and forgings.

[2]Includes scavenger, deoxidizer, and powder.

TABLE 7

U.S. STOCKS AND CONSUMPTION OF NEW AND OLD MAGNESIUM SCRAP[1]

(Metric tons)

Year	Stocks, Jan. 1	Receipts	Consumption			Stocks, Dec. 31
			New scrap	Old scrap	Total	
1989	787	7,233	3,052	4,269	7,321	699
1990	699	6,913	2,948	4,277	7,225	387

[1]Cast scrap, solid wrought scrap, borings, turnings, and drosses.

began a feasibility study in 1988 on a plant to recover magnesium from asbestos tailings with technology developed by Noranda and were satisfied with results to date. Government agencies, both Federal and provincial, reportedly financed one-half of the cost for the feasibility study and may provide further support in the forms of tax incentives and a break on real estate costs. The proposed plant, named Magnola, would use available asbestos tailings from a nearby mine that have a 25% magnesium content as the feed material.

India.—Officials from Southern Magnesium and Chemicals Ltd. stated that magnesium production from plants with a combined annual capacity of 1,200 tons began in April. Production from these plants was expected to be sufficient to supply the country's annual demand of 800 to 1,000 tons.

Norway.—Norsk Hydro planned to temporarily close 8,000 to 10,000 tons of annual capacity at its Porsgrunn magnesium complex early in the year for what the company termed as rearrangements. With additional production capacity available from its new Canadian plant, Norsk Hydro estimated that total 1990 production from both its plants would be 75,000 to 80,000 tons.

Brazil's Rima Group and Elkem A/S reportedly were negotiating to construct a 20,000- to 25,000-ton-per-year magnesium plant in Norway using Rima's technology. A feasibility study was underway, and if the decision is made to construct a plant, construction was expected to begin in 1991. The proposed plant, scheduled for completion in 1993, would be near one of Elkem's existing plants to take advantage of infrastructure already in place.

United Kingdom.—Norsk Hydro reportedly completed construction of a 4,500-ton-per-year magnesium granule production plant in Immingham in November. Magnesium ingots were imported from Norway and were reduced to granules 0.2 to 1 millimeter in diameter. These granules were to be used for steel desulfurization, and magnesium powder was produced as a byproduct for use in the pyrotechnic and chemical industries. European markets were the main target for the plant's output.

Magnesium Compounds

Production.—Caustic-calcined magnesia production was stable during the year, and dead-burned magnesia production declined about 4%. Production of olivine dropped by about 5%, and the average value decreased approximately 6%.

In June, National Refractories & Minerals Corp. signed an agreement with Radex Heraclith AG of Austria for Radex to acquire 50% ownership of National Refractories & Minerals over a 5-year period. The transaction was designed to broaden the geographical markets for both companies; National Minerals &

TABLE 8
U.S. EXPORTS OF MAGNESIUM, BY COUNTRY

Country	Waste and scrap		Metal		Alloys (gross weight)		Powder, sheets, tubing, ribbons, wire, other forms (gross weight)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989:								
Argentina	—	—	483	$1,652	—	—	26	$136
Australia	—	—	2,143	6,871	—	—	215	915
Bahrain	—	—	125	356	—	—	—	—
Brazil	152	$397	811	2,534	1	$4	496	1,685
Canada	48	129	7,225	17,254	1,410	5,615	4,906	13,135
China	—	—	199	698	—	—	—	—
Germany, Federal Republic of	18	37	—	—	1,209	5,229	135	792
Ghana	—	—	279	960	—	—	—	—
Hong Kong	—	—	(1)	5	21	36	1	13
India	—	—	508	1,829	5	196	1	24
Italy	73	205	73	1,255	17	80	14	264
Japan	42	70	11,233	32,701	157	714	647	3,490
Korea, Republic of	33	89	838	2,563	193	1,062	141	629
Mexico	925	2,079	989	3,209	99	319	357	807
Netherlands	21	43	14,990	39,522	164	477	394	1,207
Norway	—	—	1,211	3,485	2	5	—	—
Spain	—	—	738	2,446	—	—	—	—
Sweden	—	—	42	395	(1)	4	21	119
Taiwan	—	—	512	1,692	20	68	44	123
Turkey	20	40	—	—	—	—	—	—
United Arab Emirates	9	21	161	694	—	—	13	76
United Kingdom	19	41	202	1,171	30	126	124	1,526
Venezuela	17	70	61	133	—	—	228	767
Other	[r]29	[r]65	[r]410	[r]2,084	[r]521	[r]1,560	[r]380	[r]2,376
Total	1,406	3,286	43,233	123,509	3,849	15,495	8,143	28,084
1990:								
Argentina	—	—	432	1,337	—	—	40	163
Australia	—	—	2,468	7,175	—	—	149	639
Bahrain	—	—	507	1,277	—	—	—	—
Brazil	244	797	425	1,401	53	135	95	290
Canada	42	107	5,246	15,886	3,325	9,786	1,033	4,706
China	—	—	267	726	—	—	(1)	29
Germany, Federal Republic of	20	45	—	—	54	267	175	2,556
Ghana	—	—	122	366	—	—	—	—
Hong Kong	—	—	39	116	199	1,612	1	12
India	—	—	184	421	1	11	24	174
Italy	55	162	91	1,108	318	888	5	62
Japan	9	17	11,839	39,379	56	458	519	3,721
Korea, Republic of	—	—	873	2,206	129	664	442	1,115
Mexico	285	641	1,221	3,508	91	245	667	1,699
Netherlands	169	424	14,721	38,215	289	741	231	761

See footnotes at end of table.

TABLE 8—Continued

U.S. EXPORTS OF MAGNESIUM, BY COUNTRY

Country	Waste and scrap		Metal		Alloys (gross weight)		Powder, sheets, tubing, ribbons, wire, other forms (gross weight)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1990—Continued								
Norway	—	—	924	$2,431	(1)	$14	(1)	$7
Spain	—	—	650	2,412	—	—	(1)	3
Sweden	—	—	243	782	1	40	34	131
Taiwan	—	—	591	1,587	3	17	23	116
Turkey	125	$288	—	—	(1)	4	7	26
United Arab Emirates	—	—	183	505	1	12	1	5
United Kingdom	10	17	58	662	12	215	184	1,046
Venezuela	—	—	357	1,084	2	11	237	753
Other	8	24	441	2,130	99	930	485	3,113
Total	967	2,522	41,882	124,714	4,633	16,050	4,352	21,127

[r] Revised.

[1] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF MAGNESIUM, BY COUNTRY

Country	Waste and scrap		Metal		Alloys (magnesium content)		Powder, sheets, tubing, ribbons, wire, other forms (magnesium content)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989:								
Canada	3,015	$6,890	247	$998	651	$3,147	32	$127
France	—	—	—	—	31	232	—	—
Germany, Federal Republic of	60	113	—	—	26	77	—	—
Italy	—	—	—	—	129	440	—	—
Mexico	333	249	1	2	—	—	774	2,740
Netherlands	155	264	—	—	—	—	—	—
Norway	—	—	3,479	10,895	2,747	8,431	1	2
United Kingdom	60	111	54	173	245	2,375	1	59
Other	150	229	98	305	—	—	—	—
Total	3,773	7,856	3,879	12,373	3,829	14,702	808	2,928
1990:								
Canada	3,346	7,221	14,562	42,489	2,436	9,540	57	224
France	—	—	248	688	2	37	—	—
Germany, Federal Republic of	64	105	—	—	2	29	—	—
Italy	34	78	—	—	36	98	—	—
Mexico	214	161	33	82	—	—	1,107	3,981
Netherlands	281	434	—	—	—	—	—	—
Norway	—	—	1,166	3,481	2,624	7,946	—	—
United Kingdom	1	2	—	—	238	2,911	32	208
Other	135	136	130	285	6	165	1	7
Total	4,075	8,137	16,139	47,025	5,344	20,726	1,197	4,420

Source: Bureau of the Census.

TABLE 10

WORLD ANNUAL PRIMARY MAGNESIUM PRODUCTION CAPACITY,[1] DECEMBER 31, 1990

(Metric tons)

Continent and Country	Capacity
North America:	
Canada	61,500
United States	179,000
Total	240,500
South America: Brazil	10,600
Europe:	
France	15,000
Italy	10,000
Norway	41,000
U.S.S.R.	95,000
Yugoslavia	7,000
Total	168,000
Asia:	
China	9,000
India	600
Japan	13,000
Total	22,600
World total	441,700

[1] Includes capacity at operating plants as well as at plants on standby basis.

TABLE 11

MAGNESIUM: WORLD PRIMARY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1986	1987	1988	1989	1990[e]
Brazil	4,356	5,488	5,865	6,200	8,700
Canada[e]	5,100	8,800	7,600	7,200	25,300
China[e]	3,000	3,000	3,200	3,200	3,400
France	13,361	13,601	[r]13,776	[r]14,600	14,000
Italy	12,417	7,626	5,436	[r]5,469	5,400
Japan	8,116	8,180	9,012	[r]8,381	[2]12,843
Norway	56,522	56,907	50,300	49,827	[2]48,222
U.S.S.R.[e]	89,000	90,000	91,000	91,000	88,000
United States	125,639	124,396	141,983	152,066	[2]139,333
Yugoslavia	4,897	5,932	6,176	[r]6,100	6,000
Total	322,408	323,930	[r]334,348	[r]344,043	351,198

[e] Estimated. [r] Revised.

[1] Table includes data available through June 21, 1991.

[2] Reported figure.

Refractories' products were sold primarily in the United States and the Pacific rim, and Radex's were marketed mainly in Europe. In addition to marketing cooperation, the two companies were planning on technical cooperation. During the same month, National Refractories & Minerals announced that it opened a new research center in Livermore, CA, for developing and testing refractories and minerals used in chemical and building material markets. A review of minerals producers in the Southwest United States discussed processing at National Refractories & Minerals, as well as Marine Magnesium Corp. and Basic Inc.[10]

In January, Asea Brown Boveri Inc. announced that it planned to sell the minerals subsidiaries of Combustion Engineering Inc. that it acquired in late 1988. Combustion Engineering owned the country's sole magnesite producer, Basic Inc., as well as Basic Magnesia Inc., which produced magnesium compounds from seawater in Florida. By yearend, no buyer was found for these operations.

Consumption and Uses.—Dead-burned magnesia refractories for use in metal, cement, and glass production furnaces continued to be the primary application for magnesium compounds in the United States. In 1990, agricultural applications (animal feed and fertilizer) were the dominant use for caustic-calcined magnesia, accounting for 36% of U.S. shipments. Chemical processing was the next largest segment, with 19% of total shipments. The following categories, with the individual components in parentheses in declining order, were the remaining end-use sectors for caustic calcined magnesia: metallurgical (refractories, electrical, water treatment, stack-gas scrubbing, and foundry), 18%; manufacturing (rayon, fuel additives, rubber, pulp and paper, and uranium processing), 17%; construction (oxychloride and oxysulfate cements, general construction, and insulation), 3%; pharmaceuticals and nutrition (medicinal and pharmaceutical, sugar, and candy), 3%; and unspecified uses, 4%.

Magnesium carbonate and magnesium sulfate were used principally in the chemical and pharmaceutical industries. Magnesium sulfate also was used in smaller quantities for animal feed and pulp and paper manufacturing. Magnesium hydroxide was used primarily in the pulp and paper and chemical industries. Magnesium chloride was used for oxychloride cements and in the chemical industry. Magnesium chloride brines were used for road dust control and chemical production.

Foundry applications accounted for 74% of domestic olivine shipments. Refractory uses represented 10%, slag control accounted for 5%, and the remaining 11% of olivine consumption was unspecified.

Markets and Prices.—Yearend prices for magnesium compounds, quoted in the Chemical Marketing Reporter, did not change from those at yearend 1989, with the exception of magnesium sulfate prices, which increased 1 cent per pound.

Foreign Trade.—Trade data for olivine were combined with data for other material by the Bureau of the Census and could not be separately identified. The Journal of Commerce Port Import/Export Reporting Service (PIERS) provides some data on materials that are transported by ship and gives some data on olivine. According to PIERS, 110,573 tons of olivine was imported from Norway during 1990. U.S. exports of olivine were 2,107 tons; Chile, 53%, and Peru, 39%, were the primary recipients.

TABLE 12

MAGNESIUM: WORLD SECONDARY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1986	1987	1988	1989	1990[e]
Brazil	1,767	1,376	[r]1,519	[r][e]1,600	1,600
Japan	[r]13,400	10,284	[r]10,109	[r]12,075	12,500
U.S.S.R.[e]	8,000	8,000	8,000	8,000	7,500
United Kingdom[e]	1,000	1,000	1,000	1,000	1,000
United States	41,807	45,165	50,207	51,200	[2]50,262
Total	[r]65,974	65,825	[r]70,835	[r]73,875	72,862

[e]Estimated. [r]Revised.

[1] Table includes data available through June 21, 1991.

[2] Reported figure.

TABLE 13

SALIENT MAGNESIUM COMPOUND STATISTICS

(Thousand metric tons and thousand dollars)

	1986	1987	1988	1989	1990
United States:					
Caustic-calcined and specified magnesias:[1]					
Shipped by producers:[2]					
Quantity	86	103	124	135	135
Value	$33,969	$27,565	$36,500	$39,529	$37,850
Exports, value[3]	$13,295	$14,167	$13,322	$2,263	$1,406
Imports for consumption, value[3]	$11,493	$4,575	$2,371	$13,657	$13,957
Refractory magnesia:					
Shipped by producers:[2]					
Quantity	249	296	371	348	335
Value	$73,172	$80,760	$103,400	$97,673	$94,962
Exports, value	$5,488	$3,240	$9,262	$10,685	$19,709
Imports for consumption, value	$36,718	$41,333	$42,885	$38,555	$32,858
Dead-burned dolomite:					
Sold and used by producers:					
Quantity	385	259	[r]413	[r]365	342
Value	$27,789	$21,766	[r]$30,182	[r]$28,294	$26,988
World production (magnesite)	[r]12,348	[r]11,356	[r]11,381	[r]11,343	[e]10,713

[e]Estimated. [r]Revised.

[1] Excludes caustic-calcined magnesia used in the production of refractory magnesia.

[2] Includes magnesia used by producers.

[3] Caustic-calcined magnesia only.

***World Review.*—Australia.**—Development of the Kunwarara magnesite deposit near Rockhampton, Queensland, progressed considerably during 1990. The three partners in the project, Pancontinental Mining Ltd., Australia; Radex-Heraclith, Austria; and Queensland Metals Corp. NL (QMC), Australia, awarded a contract for construction of the mine and beneficiation plant in August. These companies also reached an agreement with Bridge Oil Ltd. and Petroz NL for the purchase of natural gas to fuel the plant. Commissioning of the first stage of the plant was scheduled for the third quarter of 1991. At full annual capacity, the plant will produce 150,000 tons of dead-burned magnesia and 25,000 tons of fused magnesia. Reserves at the deposit were estimated to be 800 million tons, with 400 million tons of low-iron cryptocrystalline magnesite.

During the year, QMC was operating a pilot plant to produce high-purity magnesium chloride as feed for magnesium metal production, and the company was producing caustic-calcined magnesia at the pilot plant. QMC was engaged in joint research with Queensland Cement Ltd. to develop new stable magnesium cements and building products.

Mineral Holdings Australia Pty. Ltd. reportedly was seeking a partner to start a fused magnesia, alumina, and zirconia industry in Tasmania. This project would use the Cann Creek magnesite deposit and some magnesite from the company's mines to the south of Cann Creek. Imported feed would be used for the fused alumina and zirconia.

Czechoslovakia.—The State magnesite producer, Slovenske Magnezitove Zavody (SMZ), planned to implement two projects to improve its competitiveness in a free market economy. Although much of its production was exported predominantly to the U.S.S.R. and other centrally planned economy countries in the past, which have less advanced steel and cement operations, SMZ wanted to improve its technology and products without losing this market. The first of the new projects involved chemical treatment of magnesite to produce a low-iron magnesite with a grade of 99.5% MgO for magnesia-chrome brick manufacture. The second was production of the highest quality magnesite by flotation for brick manufacture. Planned annual capacities for these projects, which were due onstream in 1991, were 26,000 tons and 15,000 tons, respectively.[11]

Greece.—Exploration and drilling work by Grecian Magnesite S.A. at its Carkara magnesite deposit resulted in defining the deposit to contain 1.6 million tons of proven reserves. A number of grades were identified, including a low-iron grade, averaging 46.5% MgO. After completing the exploration work, Grecian Magnesite planned to begin mining the deposit in late 1990 at an estimated kiln-feed production rate of 50,000 tons per year. Part of the new production will be for dead-burned magnesia and part for caustic-calcined magnesia.

Iran.—A 21,000-ton-per-year MgO production facility reportedly came on-stream in Birjand at the end of the first quarter. Ore for the $28 million plant was mined from seven deposits nearby, with total reserves estimated at 2.5 million tons.

Ireland.—By November, two new shaft kilns were operational at Premier Periclase Ltd.'s seawater magnesia plant in Drogheda, County Louth. The 50,000-ton-per-year kilns replaced existing rotary kilns at a cost of $16.5 million. With the commissioning of these new kilns, Premier will have the capability to produce large-crystal-size, low-boron magnesia for a wide range of applications, including magnesia-carbon refractories, for the most severe wear areas in oxygen and electric steelmaking furnaces. All of the company's production was exported, with its major markets in Austria, the Federal Republic of Germany, the United Kingdom, and the United States.[12]

Mexico.—Química del Mar SA de CV completed modifications at its seawater magnesia plant near Tampico early in the

TABLE 14

U.S. MAGNESIUM COMPOUNDS SHIPPED AND USED

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined[1] and specified (USP and technical) magnesias	134,641	$39,529	134,727	$37,850
Magnesium hydroxide [100% $Mg(OH)_2$][1]	341,933	70,260	366,016	69,280
Magnesium sulfate (anhydrous and hydrous)	63,432	19,819	55,411	17,366
Precipitated magnesium carbonate[1]	2,332	641	2,821	703
Refractory magnesia	348,316	97,673	335,341	94,962

[1] Excludes material produced as an intermediate step in the manufacture of other magnesium compounds.

TABLE 15

YEAREND MAGNESIUM COMPOUND PRICES

Material		Price
Magnesia, natural, technical, heavy, 85%, f.o.b. Nevada	per short ton	$232
Magnesia, natural, technical, heavy, 90%, f.o.b. Nevada	do.	265
Magnesium chloride, hydrous, 99%, flake	do.	290
Magnesium carbonate, light, technical (freight equalized)	per pound	$0.73-.78
Magnesium hydroxide, National Formulary, powder (freight equalized)	do.	.78
Magnesium sulfate, technical	do.	.15

Source: Chemical Marketing Reporter.

TABLE 16

U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined magnesia:				
Canada	2,228	$1,022	66	$30
Germany, Federal Republic of	199	128	351	262
Mexico	871	306	170	92
Netherlands	858	536	1,444	800
Other	219	271	282	222
Total	4,375	2,263	2,313	1,406
Dead-burned and fused magnesia:				
Australia	1,027	316	24	34
Belgium	417	138	326	112
Canada	11,574	5,960	53,742	16,990
France	2,626	676	1,253	321
Israel	—	—	569	397
Korea, Republic of	482	249	424	229
Mexico	5,357	2,804	577	819
Taiwan	585	298	388	157

TABLE 16—Continued

U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Dead-burned and fused magnesia—Continued				
Venezuela	206	$59	993	$449
Other	251	185	314	201
Total	22,525	10,685	58,610	19,709
Other magnesia:				
Australia	311	456	164	201
Brazil	102	91	49	50
Canada	505	282	26,672	9,679
Colombia	180	309	229	388
France	187	77	820	274
Germany, Federal Republic of	2,273	1,206	101	58
Israel	1,942	643	6	38
Italy	190	63	203	156
Korea, Republic of	55	37	131	125
Mexico	548	747	6,396	2,864
Netherlands	41	515	216	76
Panama	116	11	71	57
Spain	2,023	1,016	1,320	688
Sweden	302	100	174	87
Taiwan	159	103	179	83
Thailand	123	63	191	104
United Kingdom	141	84	256	309
Venezuela	6,319	2,743	353	217
Other	[r]326	[r]667	216	654
Total	15,843	9,213	37,747	16,108
Crude magnesite:				
Australia	124	117	77	90
Belgium	185	331	204	454
Brazil	394	906	404	1,114
Canada	1,365	668	309	127
Germany, Federal Republic of	433	542	708	1,032
Greece	180	226	162	192
Hong Kong	—	—	195	171
Italy	1,214	1,119	895	1,105
Korea, Republic of	215	109	125	74
Martinique	—	—	519	83
Mexico	4,583	2,757	1,033	426
Netherlands	217	277	1,107	1,213
New Zealand	90	117	288	194
Romania	165	98	—	—
Spain	468	389	435	498
Taiwan	255	194	395	473
Venezuela	—	—	836	250
Other	[r]492	[r]449	317	564
Total	10,380	8,299	8,009	8,060

See footnote at end of table.

TABLE 16—Continued

U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Calcined dolomite:				
Canada	22,109	$6,323	1,398	$277
Colombia	1,046	185	200	25
Germany, Federal Republic of	—	—	360	122
Mexico	9,330	1,977	7,658	1,594
Peru	1,500	476	—	—
Saudi Arabia	—	—	505	60
Spain	2,000	659	—	—
Trinidad	956	163	—	—
Venezuela	2,500	847	—	—
Other	198	53	258	135
Total	39,639	10,683	10,379	2,213

[r] Revised.

Source: Bureau of the Census.

TABLE 17

U.S. EXPORTS OF MAGNESIUM COMPOUNDS

Year	Magnesium hydroxide and peroxide		Magnesium chloride (anhydrous and other)		Magnesium sulfate (natural kieserite and epsom salts)		Magnesium sulfate (other)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989	12,072	$3,673	2,201	$1,812	95	$96	483	$519
1990	6,342	6,245	4,763	6,468	241	393	2,816	1,059

Source: Bureau of the Census.

TABLE 18

U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined magnesia:				
Canada	56,069	$10,996	48,859	$9,988
China	7,569	808	18,896	1,525
Greece	6,456	789	9,939	1,406
Mexico	3,203	416	2,390	325
Spain	—	—	2,200	266
Turkey	2,108	534	1,482	328
Other	179	114	119	119
Total	75,584	13,657	83,885	13,957
Dead-burned and fused magnesia:				
Canada	9,746	4,582	3,743	2,095
China	61,382	4,914	67,905	7,293
Czechoslovakia	12,159	948	2,549	374
Greece	45,346	7,800	28,242	4,079
Hong Kong	4,230	414	—	—

TABLE 18—Continued

U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Dead-burned and used magnesia—Continued				
Ireland	13,551	$4,467	7,892	$2,694
Israel	1,122	404	7,592	2,818
Japan	11,384	2,955	6,616	2,451
Mexico	25,050	7,832	24,954	9,224
Netherlands	3,186	1,056	2,110	683
United Kingdom	15,484	3,107	3,233	1,008
Other	150	76	174	139
Total	202,790	38,555	155,010	32,858
Other magnesia:				
Canada	390	123	280	57
China	—	—	162	347
Germany, Federal Republic of	60	86	101	299
Israel	181	305	602	1,382
Japan	4,226	7,591	3,440	5,972
Mexico	335	156	—	—
United Kingdom	370	394	148	195
Other	[r]312	[r]539	304	321
Total	5,874	9,194	5,037	8,573
Crude magnesite:				
Canada	1,077	225	52	7
China	6,344	645	23	4
Denmark	—	—	100	23
France	158	66	18	10
Germany, Federal Republic of	55	8	524	66
Italy	259	127	622	180
Japan	424	250	526	360
Other	[r]55	[r]33	92	72
Total	8,372	1,354	1,957	722
Calcined dolomite:				
Canada	20,854	2,755	38,074	3,596
Germany, Federal Republic of	194	41	36	11
Ireland	10	4	—	—
Mexico	730	71	331	32
Total	21,788	2,871	38,441	3,639

[r] Revised.

Source: Bureau of the Census.

TABLE 19

U.S. IMPORTS FOR CONSUMPTION OF MAGNESIUM COMPOUNDS

Year	Magnesium hydroxide and peroxide		Magnesium chloride (anhydrous and other)		Magnesium sulfate (natural kieserite)		Magnesium sulfate (natural epsom salts)		Magnesium sulfate (other)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989	1,792	$3,091	5,994	$1,202	11,781	$540	166	$33	9,269	$2,076
1990	3,548	5,456	6,914	1,477	12,548	612	44	37	9,992	1,656

Source: Bureau of the Census.

TABLE 20

WORLD MAGNESIUM COMPOUNDS ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1990

(Thousand metric tons, MgO equivalent)

Continent and Country	Raw material	
	Magnesite	Seawater or brines
North America:		
Canada	160	—
Mexico	—	170
United States	100	912
Total	260	1,082
South America: Brazil	345	—
Europe:		
Austria	576	—
Czechoslovakia	700	—
France	—	30
Greece	652	—
Ireland	—	100
Italy	—	125
Netherlands	—	120
Norway	—	25
Poland	10	—
Spain	205	—
Turkey	285	—
U.S.S.R.	2,100	100
United Kingdom	—	200
Yugoslavia	240	—
Total	4,768	700
Africa:		
Kenya	170	—
South Africa, Republic of	119	—
Zimbabwe	2	—
Total	291	—
Asia:		
China	1,000	10
India	214	—
Israel	—	70
Japan	—	485
Korea, North	1,250	—
Korea, Republic of	—	50
Nepal	125	—
Total	2,589	615
Oceania: Australia	24	—
Grand total	8,277	2,397

[1] Includes capacity at operating plants as well as at plants on standby basis.

TABLE 21

MAGNESITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1986	1987	1988	1989	1990^{e}
Australia	41,441	53,941	56,446	^{e}55,000	60,000
Austria	1,084,360	946,943	1,121,585	^{r}1,205,000	1,200,000
Brazil[2]	296,792	390,182	^{r}404,126	^{r}259,508	350,000
Canada^{e} [3]	144,000	150,000	150,000	150,000	150,000
China^{e}	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
Colombia	14,936	^{r}15,444	^{r}17,760	^{r}20,425	20,000
Czechoslovakia	666,000	671,000	630,786	^{e}600,000	600,000
Greece	^{r}944,000	^{r}842,000	^{r}847,000	^{r}850,000	860,000
India	422,000	430,000	^{r}507,873	^{r}479,530	500,000
Iran^{e} [4]	^{r}2,240	^{r}2,240	^{r}2,500	^{r}2,800	3,000
Kenya	^{e}300,000	—	—	—	—
Korea, North^{e}	1,900,000	^{r}1,500,000	^{r}1,500,000	^{r}1,500,000	1,500,000
Mexico	7,530	7,351	^{r}7,538	^{r}4,229	3,200
Nepal	63,190	38,388	45,000	^{r}27,978	25,000
Pakistan	1,757	^{r}3,824	3,081	^{r}8,750	8,000
Philippines^{e}	650	650	650	700	700
Poland	20,900	22,300	^{r}23,900	^{e}23,000	24,000
South Africa, Republic of	61,186	74,961	74,088	^{r}75,695	[5]104,182
Spain^{e}	700,000	710,000	^{r} [5]624,216	^{r}620,000	600,000
Turkey	^{r}1,306,645	^{r}1,189,667	^{r}1,125,844	^{r}1,238,123	800,000
U.S.S.R.^{e}	1,925,000	1,875,000	1,825,000	1,825,000	1,600,000
United States	W	W	W	W	W
Yugoslavia	423,000	403,000	383,000	^{r}364,000	275,000
Zimbabwe	22,649	28,991	30,121	^{r}33,423	30,000
Total	^{r}12,348,276	^{r}11,355,882	^{r}11,380,514	^{r}11,343,161	10,713,082

^{e}Estimated. ^{r}Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1] Figures represent crude salable magnesite. In addition to the countries listed, Bulgaria produced magnesite, but output is not reported quantitatively, and available general information is inadequate for formulation of reliable estimates of output levels. Table includes data available through May 3, 1991.

[2] Series reflects output of marketable concentrates. Production of crude ore was as follows, in metric tons: 1986—648,752; 1987—860,163; 1988—810,837; 1989—1,385,565; and 1990—1,000,000 (estimated).

[3] Magnesitic dolomite and brucite. Figures are estimated on the basis of reported tonnage dollar value.

[4] Year beginning Mar. 21 of that stated.

[5] Reported figure.

year. As a result of these modifications, the company switched from producing a 95% dead-burned magnesia to a low-boron, 97% dead-burned magnesia. Annual plant capacity was reduced temporarily from 70,000 tons to 45,000 tons during the switch, but by yearend, additional equipment was installed to reach the original 70,000-ton-per-year capacity. Química del Mar also was upgrading its caustic-calcined magnesia from 95% MgO to 97% MgO.[13]

South Africa, Republic of.—Mintek, a minerals and metals research organization, conducted laboratory-scale tests on seawater production of high-grade magnesia. Magnesia in the Republic of South Africa was produced from magnesite, but the grade was not high enough to be used for refractories, so the country relied on imports to meet this need. From Mintek's calculations, a 50,000-ton-per-year plant would yield an annual rate of return on investment of 15%.

Current Research.—The world's first magnesium oxide ceramic fiber reportedly was produced by a new process developed at the Department of Energy's

Argonne National Laboratory. The new process involved mixing magnesium oxide particles with a plastic binder, exposing a thin stream of the mixture to turbulent air, and firing it. Normally, ceramic fibers are made commercially by a variety of techniques that are specifically tailored to the type of fiber manufactured, and the fibers are made in batches. Researchers claimed this new process could be carried out continuously and could be used on any sinterable ceramic. Possible future uses for new ceramic fibers made by this process include electrodes for high-temperature batteries and porous substrates for catalysts.

The Lithium Div. of FMC Corp. opened a pilot plant at its Bessemer City, NC, plant to treat books by a company-developed process to extend the books' useful life. This process, which retards brittleness during aging, involves immersing the book in an organic solvent containing a magnesium compound and then removing the solvent. The magnesium compound remains in the paper and forms a buffer. FMC claims that this process can preserve the book for an additional 10 to 12 years. The pilot plant can treat up to 300,000 books per year. If the treatment is widely accepted by libraries, FMC planned to build four commercial plants that can treat 2 to 5 million books per year at a projected cost of $6 per book.

In a review of refractories consumption by the cement industry, average consumption rates of various refractories by the U.S. industry were estimated. Of the total average consumption of refractories of 1.99 pounds per ton of clinker produced, magnesia-chrome refractories constituted 29% and magnesia-spinel constituted 13% of the total. Additional information was presented on the specific areas of the kiln in which these types of refractories were normally installed.[14]

OUTLOOK

In its annual review of magnesium supply and demand, the International Magnesium Association predicted an average annual growth rate of about 3% for world primary magnesium shipments from 1989 to 1995, with the largest growth occurring in Western Europe and North America. Diecasting, at a predicted average annual growth rate of almost 10%, was the end use contributing the most to the total forecast. About 70% of magnesium diecastings worldwide were used by the automotive industry, and with the potential increase in the Corporate Average Fuel Economy rates in the United States, automobile manufacturers will continue to increase their use of magnesium components to reduce total vehicle weight.[15]

Refractories, which were the dominant use for magnesium compounds, continued to have the greatest effect on overall demand. As producers develop magnesia-base refractories that are longer lived and that can be substituted for other refractories, the overall use of these refractories will increase. Conversely, because of these characteristics, refractory linings in these furnaces will not have to be replaced as often, which will decrease demand. The synergistic effects of these trends likely will result in a stagnant demand for magnesia-base refractories.

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TABLE 22

MAGNESIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons of contained magnesium)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
WORLD PRODUCTION											
United States:											
Nonmetal	727	690	512	567	574	420	412	464	[r]573	[r]513	499
Metal	[1]153	140	93	104	144	136	125	124	142	152	139
Total	880	830	605	671	718	556	537	588	[r]715	[r]665	638
Rest of world:											
Nonmetal	4,726	4,668	4,371	4,777	4,676	4,807	[r]5,009	[r]4,723	[r]4,780	[r]4,769	[e]4,588
Metal	162	169	161	156	184	189	196	200	192	[r]192	[e]212
Total	4,888	4,837	4,532	4,933	4,860	4,996	[r]5,205	[r]4,923	[r]4,972	[r]4,961	[e]4,800
World total	5,768	5,667	5,137	5,604	5,578	5,552	[r]5,742	[r]5,511	[r]5,687	[r]5,626	[e]5,438
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
U.S. production:											
Nonmetal	727	690	512	567	574	420	412	464	[r]573	[r]513	499
Primary metal	153	140	93	104	144	136	125	124	142	152	139
Secondary metal (old scrap)	16	22	21	23	24	24	23	23	28	28	31
Imports:											
Nonmetal	46	50	39	61	115	134	160	164	198	171	147
Metal	4	6	5	5	9	8	8	11	14	12	27
Industry stocks, metal, Jan. 1	40	44	57	42	25	32	39	39	28	25	26
Total U.S. supply	986	952	727	802	891	754	767	825	[r]983	[r]901	869
Distribution of U.S. supply:											
Exports:											
Nonmetal	59	32	20	15	27	25	25	20	34	26	59
Metal	52	32	36	43	44	36	40	44	50	57	52
Industry stocks, metal, Dec. 31	44	57	42	25	32	39	39	28	25	26	26
Industrial demand[2]	831	831	629	719	788	654	663	733	[r]874	[r]792	732
U.S. DEMAND PATTERN											
Nonmetal:											
Refractories	629	609	446	508	531	402	376	453	[r]535	[r]470	413
Chemicals	85	99	85	105	131	127	171	155	[r]202	[r]188	174
Total	714	708	531	613	662	529	547	608	[r]737	[r]658	587
Metal:											
Cans and containers	19	20	17	19	23	23	22	39	39	42	45
Transportation	36	38	25	31	36	38	33	38	38	36	38
Machinery	34	34	33	34	29	22	27	19	20	17	20
Chemicals	7	8	6	7	8	5	3	2	1	1	1
Nonferrous metal production	10	13	7	6	9	12	9	5	11	12	11
Iron and steel desulfurization	NA	NA	NA	NA	10	12	12	13	15	15	16
Iron and steel foundries	5	5	4	3	4	3	3	2	3	2	1
Other	6	5	6	6	7	10	7	7	10	9	13
Total	117	123	98	106	126	125	116	125	137	134	145
Total industrial demand	831	831	629	719	788	654	663	733	[r]874	[r]792	732
Total U.S. primary demand[3]	815	809	608	696	764	630	640	710	[r]846	[r]764	701
Total U.S. demand for primary metal[4]	101	101	77	83	102	101	93	102	109	106	114

[e] Estimated. [r] Revised. NA Not available; included in "Other."

[1] Derived from production data published by the International Magnesium Association and the Canadian Department of Energy, Mines and Resources.

[2] Sum of total nonmetal and total metal demands.

[3] Total U.S. demand less U.S. recovery from secondary metal.

[4] U.S. demand for metal less U.S. recovery from secondary metal.

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